OFFICE MEMORANDUM
September 24, 2012

TO: Jim Karas, Director of Engineering

VIA: Barry Young, Engineering Manager

FROM: Jane Lundquist, Principal Air Quality Engineer

SUBJECT: Mercury Emissions from the Cremation of Human Remains

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Action Requested:
Attached for your review and approval is a report on Mercury Emissions from the Cremation of Human Remains. Upon your approval, this report will become the supporting documentation for an updated mercury emission factor in the BAAQMD Permit Handbook chapter for crematories.

Background:
The current mercury emission factor for human cremations presented in the permit handbook chapter is based on a report I had previously prepared in January 2000 using data that was available at that time. The attached report on the mercury emissions from human cremations is based on more recent data that allows for further refinement in the estimation methodology and results in a more accurate estimate.

Mercury Emissions from the Cremation of Human Remains

September 24, 2012

Bay Area Air Quality Management District

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Bay Area Air Quality Management District

Mercury Emissions from the Cremation of Human Remains

Executive Summary

The purpose of this report is to update the emission factor the District uses to estimate mercury emissions from the cremation of human remains. The previous mercury emission factor, estimated in January 2000, was based on aggregated dental statistics from the 1970's and 1980's. More recent dental statistics, 1999 through 2004, is available that is broken down on a very granular level that allows for a further refined mercury emission estimate. The emissions of mercury are assumed to be from dental amalgam fillings in the human remains that are cremated. Because mercury emissions vary significantly between individual cremations (due primarily to differences in the number and size of amalgam fillings between individuals), this mass balance approach is more appropriate than the use of an emission factor derived from results based on very few source tests.

The mercury emission factors derived from mass balance in this analysis provide a conservative estimate of mercury emissions from the cremation of human remains and accounts for the variation in the amount of dental amalgam that would be encountered in the general population. Data on dental restorations in over 27,000 individuals were used in this analysis. An average and a maximum mercury emission per human cremated are estimated by mass balance based on dental restoration statistics by age group, death statistics by age group and estimated amounts of mercury in restored dental surfaces. The mercury emission factors for human cremations in the District Permit Handbook under Section 5. Source-Specific Guidance, Chapter 11.6 Crematories should be updated to reflect the values in the table below and to specify that the estimated one-hour maximum mercury emission rate assumes that all of the mercury emissions occur in the first hour of cremation.

Mercury Emission		
Average Emission Factor	Maximum Emission Factor	Maximum One-hour Emission Rate,
0.0034 pound/body	0.013 pound/body	0.0017 grams/second

Mercury readily vaporizes at the high temperatures in which cremations occur. For the estimation of an acute short term exposure, all of the mercury is assumed to be vaporized during the first hour of cremation; this results in a maximum one-hour emission rate of 0.0017 gram (3.7 E-6 pound) of mercury per second per human cremated.

These estimates are conservative because:

- All restored bicuspid and molar teeth are assumed to be restored with amalgam; however, this is not the actual case because the use of composites and other non-amalgam materials in dental restorations has been increasing.

Mercury Emissions from the Cremation of Human Remains

- Mercury vapor is released from amalgam restorations during chewing and tooth brushing; these mercury losses over time are not deducted in the calculation of mercury emissions at the crematory.
- Mercury emission rates from human cremations are expected to decrease in the future. "Because of a general decline of dental caries among school children and young adults, the use of dental amalgam began to decrease in the 1970's. There are also changes in patterns of dental caries, largely the result of topical and systemic fluoride, sealant use, improved oral hygiene practices and products, and possibly dietary modifications. In 1990, over 200 million restorative procedures were provided in the United States; of these, dental amalgam accounted for roughly 96 million, a 38 percent reduction since 1979. This trend is expected to continue. There are also reports that carious lesions today are generally smaller, easier to treat, and managed by more conservative treatment that retains tooth structure. Because of this decrease in the frequency and size of dental caries, there has been a relative increase in the use of alternative dental restorative materials."[1]

[1] U.S. Department of Health and Human Services, Office of Disease Prevention and Health Promotion, Amalgam Use and Benefits. http://www.health.gov/environment/amalgam1/amalgamu.htm

Mercury Emissions from the Cremation of Human Remains

1. Background

The District's January 2000 estimate of mercury emissions from the cremation of human remains were based on dental statistics that were available at the time and which covered the periods 1971-1974 and 1986-1987. These statistics contained average counts of restored teeth by age group. Average mercury emissions were estimated using this data. Estimates of acute short-term health impacts using these average estimates are not conservative enough to account for cremation of individuals that have higher than average counts of restored teeth. More recent data is available on dental restorations that include the raw data used in determining the average values; this data is more granular and contains actual counts of restored surfaces for each tooth in each individual. Recent research has demonstrated that the correlation with the number of restored surfaces per tooth provides a better estimation of the weight of amalgam in teeth than estimates based only on the type of restored tooth. These more recent data are used to update the estimate of mercury emissions from the cremation human remains.

2. Data and Assumptions

An average and a maximum *mercury emission per human cremated* is estimated by mass balance based on dental restoration statistics by age group, death statistics by age group, estimated weight of amalgam in dental restorations and estimated amounts of mercury in dental amalgam. This data is described in sections 2.1 through 2.4.

2.1 Statistics on the Number of Restored Surfaces in Teeth

Data on the number of restored surfaces per tooth for each individual and the individual's age was obtained from the National Health and Nutrition Examination Survey's (NHANES) demographics and oral health data sets for the periods 1999-2000, 2001-2002 and 2003-2004. [2] NHANES data collected after 2004 was not used because the latter data sets did not have information on the number of restored surfaces. The data used in this analysis include examinations of more than 27,000 individuals, the individual's age in years at screening, and the number of restored surfaces for each tooth. A count of the number of single-surface, two-surface, three-surface, four-surface and five-surface restoration teeth was determined for each individual.

[2] Centers for Disease Control and Prevention, National Health and Nutrition Examination Survey (NHANES) demographics and oral health data.
http://www.cdc.gov/nchs/nhanes/nhanes1999-2000/demo99_00.htm
http://www.cdc.gov/NCHS/nhanes/nhanes1999-2000/exam99_00.htm
http://www.cdc.gov/nchs/nhanes/nhanes2001-2002/demo01_02.htm
http://www.cdc.gov/nchs/nhanes/nhanes2001-2002/exam01_02.htm
http://www.cdc.gov/nchs/nhanes/nhanes2003-2004/demo03_04.htm
http://www.cdc.gov/nchs/nhanes/nhanes2003-2004/exam03_04.htm

2.2 Death Statistics by Age Group for the Nine Bay Area Counties

Because the NHANES data is for an age demographic that is different from the age demographic of those who die annually, death statistics by age group for the nine Bay Area counties were used to weight the NHANES results. Death statistics were obtained from the California Department of Public Health Death Statistical Data Tables, Table 5-17 "Deaths by Age, California Counties and Selected City Health Departments." [3] For the nine Bay Area counties, the fraction of annual cremations with individuals in each age group is calculated assuming that the age demographic of those cremated each year is the same as the age demographic of those who die each year. The Table 1 shows the fraction of deaths in each age group.

Table 1 - Fraction of Annual Deaths by Age Group for the Nine Bay Area Counties

Under 5 years	5-14 years	15-24 years	25-34 years	35-44 years	45-54 years	55-64 years	65-74 years	75-84 years	Over 85 years
0.0105	0.00208	0.0120	0.0153	0.0311	0.0745	0.115	0.143	0.262	0.334

2.3 Estimated Weight of Amalgam in Restored Surfaces

Researchers have determined that the best covariate for estimating the weight of amalgam in a restored tooth is the number of restored surfaces on the tooth. The values shown in Table 2, which were reported in the Journal of the Canadian Dental Association[4], are used for estimating the amount amalgam in a tooth based on the number of restored surfaces on the tooth.

Table 2 - Weight of Amalgam in Teeth Based on the Number of Restored Surfaces

No. of surfaces restored	Least square mean weight of amalgam restorations, grams	Range for 95% Confidence Limit, grams
1 surface	0.31	0.28-0.34
2 surface	0.49	0.45-0.53
3 surface	0.81	0.76-0.86
>=4 surface	1.38	1.31-1.45

[3] California Department of Public Health Death Statistical Data Tables, Table 5-17 "Deaths by Age, California Counties and Selected City Health Departments" from the following websites:
http://www.cdph.ca.gov/data/statistics/Documents/VSC-2009-0517.pdf
http://www.cdph.ca.gov/data/statistics/Documents/VSC-2008-0517.pdf
http://www.cdph.ca.gov/data/statistics/Documents/VSC-2007-0517.pdf
http://www.cdph.ca.gov/data/statistics/Documents/VSC-2006-0517.pdf
http://www.cdph.ca.gov/data/statistics/Documents/VSC-2005-0517.pdf

[4] Adegbembo AO, Watson PA, Rokni S. Estimating the Weight of Dental Amalgam Restorations. Journal of the Canadian Dental Association January 2004, vol. 70, No. 1, 30-30e.
http://www.cda-adc.ca/jcda/vol-70/issue-1/30.html

2.4 Mercury Composition in Dental Amalgam

A factsheet on dental amalgam use was prepared for the Western Sustainability and Pollution Prevention Network. This factsheet is based on surveys of dental office amalgam use in the San Francisco area and "… assumes that amalgam contains 45% mercury, which is the average of amounts reported in MSDSs for several commonly used capsules." [5] The 45% mercury content in amalgam is also used in this analysis.

3. Calculation Method and Results

Mercury emissions from the cremation of human remains are estimated using a mass balance approach based on the assumption that the source of the mercury emissions are from dental amalgam in restored teeth. All of the mercury in the dental amalgam restorations are assumed to vaporize during cremation. The 1999-2004 NHANES oral health data was analyzed for the counts of the number of teeth with single-, two-, three-, four- and five-surface restorations for each individual examined. The amount of dental amalgam in each individual is then calculated using the counts of each type of surface restoration and the weight of amalgam in teeth based on the number of restored surfaces listed in Table 2 above. Incisor and cuspid teeth were not counted because for aesthetic reasons these front teeth are restored with non-amalgam restorative materials which match the tooth color. A 2007 Public Health Report reviewed data on amalgam usage in the United States. Based on dental insurance claim data, the study estimates that of the total restorations in 2005, 31.6% were amalgam, 46.6% were composites and 21.8% were crowns.[6] Dental amalgam is not used when looks are important, such as fillings in the front teeth. A reasonable conclusion is that incisor and cuspid teeth, which are front teeth, are not restored with amalgam; as such, incisors and cuspids are not included in the counts of teeth with surfaces that were restored with amalgam.

[5] Western Sustainability and Pollution Prevention Network, Studies: Dental Chemical Use, Fact Sheets, Dental Restorative Materials, Dental Amalgam Use October 2005, page 4, http://wsppn.org/pdf/studies/dental/Amalgam_Use%2001.pdf

[6] Beazoglou T, Eklund S, Heffley D, Meiers J, Brown LJ, Bailit H, Economic Impact of Regulating the Use of Amalgam Restorations, Public Health Reports 2007 September-October; vol. 122, 657 http://www.publichealthreports.org/issueopen.cfm?articleID=1934

Mercury Emissions from the Cremation of Human Remains

The following equation was used to calculate the amount of dental amalgam for each individual:

$$A = \sum C_i \times F_i$$

where
- A = amount of dental amalgam in each individual, g
- $_i$ = number of restored surfaces (i = 1, 2, 3, 4 and 5)
- C_i = count of the number of teeth (excluding incisors and cuspids) with "i" number of restored surfaces
- F_i = amalgam weight for a tooth with "i" number of restored surfaces

For the purpose of estimating mercury emissions for short-term acute impacts, the amount of amalgam in the fillings of an individual representing the 95th percentile is used: 95 percent of the individuals will have amounts of amalgam fillings that are less than the individual representing the 95th percentile. The choice of the 95th percentile value follows OEHHAs use of 95th percentile values for exposure assessment. For the purpose of estimating mercury emissions for chronic long-term impacts, the average amount of amalgam in individuals is used.

The age demographic for those examined in the NHANES study do not represent the age demographic for the deceased that are cremated. Older individuals typically have more restored teeth and larger percentages of older individuals die. Thus, the individual at the 95th percentile among the cremated is expected to have more dental amalgam than the individual at the 95th percentile in the NHANES study. To adjust for this difference, the NHANES data was sorted by age groups, the 95th percentile and average results in each age group was weighted by the fraction of deaths within each age group, and the weighted results summed to get the final result used to estimate mercury emissions from the cremation of human remains. Table 3 shows the age groups, the number of individuals examined in the age group, the 95th percentile and average results from the NHANES study, the fraction of deaths in the Bay Area, the weighted values (NHANES value multiplied by the fraction of deaths) and the summed weighted values that represent the results for the deceased.

Mercury Emissions from the Cremation of Human Remains

Table 3 - Estimating Amounts of Dental Amalgam in Deceased						
Age group, years	Number of individuals in the age group	Dental amalgam in NHANES individual at 95%-tile, grams	Average dental Amalgam in NHANES individual, grams	Fraction of deaths in the Bay Area	Weighted dental amalgam in individual at 95%-tile, grams	Weight average dental amalgam in individual, grams
Over 85	469	13.23	2.96	0.335	4.43	0.99
75 – 84	1407	14.33	3.65	0.262	3.76	0.96
65 – 74	1942	14.73	3.78	0.143	2.10	0.54
55 – 64	1907	14.94	4.32	0.115	1.71	0.50
45 – 54	2162	13.47	4.31	0.074	1.00	0.32
35 – 44	2435	10.40	3.29	0.031	0.32	0.10
25 – 34	2512	7.39	2.23	0.015	0.11	0.03
15 – 24	5643	4.62	1.07	0.012	0.06	0.01
5 – 14	6523	3.66	0.72	0.002	0.01	0.00
Under 5	2045	0.49	0.16	0.011	0.01	0.00
Sum for Dental Amalgam in deceased at the 95%-tile, grams					**13.51**	
Sum for Average Dental Amalgam in deceased, grams						**3.46**

Mercury emissions from the cremation of human remains for acute health impacts are based on the amount of dental amalgam present in the deceased representing the highest amount at the 95th percentile and the emissions for chronic impacts are based on the average amount of dental amalgam present in the deceased. Using a dental amalgam mercury content of 45 weight percent, estimated mercury emissions from a human cremation are calculated for use in determining acute and chronic impacts and presented in Table 4.

Table 4 - Mercury Emission Rates for the Cremation of Human Remains		
Acute Impacts (95%tile)	6.1 g/human cremated	0.013 lbs./human cremated
Chronic Impacts (average)	1.6 g/human cremated	0.0034 lbs./human cremated

For comparison, the 95th percentile and the average amount of mercury in amalgam restored surfaces for all the individuals in the NHANES oral health study is presented in Table 5. The values in Table 4, which are weighted by the fraction of deaths within the age group to reflect the cremated demographic, are significantly higher that the values in Table 5, which are unweighted.

Table 5 - Mercury Content in Dental Amalgam Restorations for NHANES Study		
95th percentile	4.5 g/individual	0.0099 lbs./individual
Average	0.93 g/individual	0.0021 lbs./individual

4. Conservative Assumptions

The following conservative assumptions were made in estimating the mercury emission rates presented in table 4:

1. All of the bicuspid and molar restored surfaces counted in the NHANES study are assumed to be restored with dental amalgam, but not all bicuspid and molar surface restorations are made with dental amalgam. The use of dental amalgam has been decreasing with the increasing use of other dental restoration materials such as composite resins and glass ionomer cement. Bicuspid and molars represent more than half the number of total teeth. The 2007 Public Health Report estimates total amalgam placements in 2005 as being approximately 31.6% of the total of restorations, 46.6% were composites and 21.8% were crowns.
2. None of the mercury in the amalgam that is initially placed is assumed to be lost over time. However, "…data suggest that mercury is continuously released in the oral cavity from amalgam dental restorations. The rate release is dependent upon many factors including: area, age, and composition of the amalgam, as well as the quality of the surface oxide layer. … Intraoral mercury vapor levels were directly correlated with the number of amalgam fillings" [7]
3. The estimated mercury emissions from a human cremation due to dental amalgam surface restoration are static values. However, the 2007 Public Health Report study, which also analyzed trends for amalgam placements, concluded that "…the mean percent of decline in the number of amalgams inserted per year for the past 12 years was 3.7%. This rate of decline did not vary by age group or year. … It is expected that this trend will continue into the foreseeable future." [8] Over the next few decades, age-specific rates of restorations are expected to decline markedly in older age groups. This in turn will result in lower mercury emission rates from the cremation of human remains in the future.

[7] U.S. Department of Health and Human Services, Office of Disease Prevention and Health Promotion, Appendix III Evaluation of Risk Associated with Mercury Vapor from Dental amalgam. http://www.health.gov/environment/amalgam1/appendixIII.htm

[8] Beazoglou T, Eklund S, Heffley D, Meiers J, Brown LJ, Bailit H, Economic Impact of Regulating the Use of Amalgam Restorations, Public Health Reports 2007 September-October; vol. 122, 657 http://www.publichealthreports.org/issueopen.cfm?articleID=1934

5. Comparison with Other Estimates

Table 6 shows a comparison of the mercury emission estimates from human cremations from this analysis, the District's January 2000 estimate, the California Air Toxics Emission Factor Database (CATEF) and the EPA's Locating and Estimating Air Emissions from Sources of Mercury and Mercury Compounds (L&E).

Table 6 - Comparison of Estimates of Mercury Emissions from Human Cremations, lbs. /body

Reference for Emission Estimate	Average	Low	High	Basis
Estimated in this report	0.0034	not estimated	0.013	1999-2004 Dental restoration statistics for more than 27,000 individuals and filling size data for the number of surfaces restored
BAAQMD 2000 estimate	0.0011	not estimated	not estimated	1970s and 1980s data on the average number of fillings based on more than 30,000 individuals examined; no data on filling size
California Toxics Emission Factor Database [9]	0.0049	0.0048	0.005	Less than 3 sources were tested; no data on the number or size of fillings
Locating and Estimating Air Emissions from Sources of Mercury and Mercury Compounds [10]	0.0033	0.0014	0.0049	Three source tests; no data on the number or size of fillings

For the purpose of estimating mercury emissions for short-term acute impacts, the amount of amalgam in the fillings of an individual representing the 95th percentile is used: 95 percent of the individuals will have amounts of amalgam fillings that are less than the individual representing the 95th percentile. The high value of 0.013 pounds of mercury emitted per body cremated estimated in this report occurs for the 95% percentile.

5. Conclusion

The mercury emission factors derived from mass balance in this analysis provide a conservative estimate of mercury emissions from the cremation of human remains and accounts for the variation in the amount of dental amalgam that would be encountered in the general population. Data on dental restorations in over 27,000 individuals were used in this analysis. The mercury emission factors for human cremations in the District

[9] CATEF - California Air Toxics Emission Factor Database. California EPA Air Resources Board http://www.arb.ca.gov/app/emsinv/catef_form.html

[10] Locating and Estimating Air Emissions from Sources of Mercury and Mercury Compounds. EPA-454/R-97-012, December 1997

Mercury Emissions from the Cremation of Human Remains

Permit Handbook under Section 5. Source-Specific Guidance, Chapter 11.6 Crematories should be updated to reflect the values in the table below and to specify that the estimated one-hour maximum mercury emission rate assumes that all of the mercury emissions occur in the first hour of cremation.

Mercury Emission		
Average Emission Factor	Maximum Emission Factor	Maximum One-hour Emission Rate,
0.0034 pound/body	0.013 pound/body	0.0017 grams/second